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THE WR-1 CORROSION TEST FACILITY

by

E. V. Murphy and G. R. Simmons

Whiteshell Nuclear Research Establishment
Pinawa, Manitoba R0E 1L0

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L'APPAREIL D'ESSAI DE CORROSION DE WR-1

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RESUME

Ce rapport décrit le nouvel appareil d'essai de corrosion récemment installé dans le réacteur de recherche à caloporteur organique. L'appareil d'irridiation est un simple élément introduit dans une case du réseau du réacteur et qui peut envoyer un flux de neutrons rapides d'une densité de 2.65×10^{17} neutrons/($m^2 \cdot s$) sur des échantillons sous irridiation. Un circuit autonome d'eau de refroidissement contrôlée chimiquement dissipe la chaleur gamma et neutronique produite dans l'élément introduit et dans les échantillons. Les températures des échantillons varient normalement entre 245°C et 280°C dans toute la partie centrale de l'élément introduit.

Energie Atomique du Canada Limitée
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ABSTRACT

This report describes a new Corrosion Test Facility which has recently been installed in the WR-1 organic-cooled research reactor. The irradiation facility is a single insert, installed in a reactor site, which can deliver a fast neutron flux density of 2.65×10^{17} neutrons/$(m^2 \cdot s)$ to specimens under irradiation. A self-contained controlled-chemistry cooling water circuit removes the gamma- and neutron-heat generated in the insert and specimens. Specimen temperatures typically vary from 245°C to 280°C across the insert core region.

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CONTENTS

1. INTRODUCTION

The development of structural materials for in-reactor use requires that the physical, mechanical and corrosion properties of the materials be tested extensively under irradiation conditions. There are several facilities available in the WR-1 reactor for examination of the effects of irradiation on the physical and mechanical properties of materials. These facilities include the Static Irradiation Rig[1], the Biaxial Creep Rigs[2], the Uniaxial Creep Rigs[3] and the Material Irradiation Facilities[4]. However, there was no facility available which would allow study of the effects of irradiation on the corrosion properties of potential structural materials under controlled chemistry conditions. This report describes such a facility which has recently been installed in the WR-1 research reactor.

2. THE WR-1 REACTOR

The WR-1 reactor is a 54 MW(t) organic-cooled, heavy-water-moderated, vertical pressure-tube reactor. It consists of a 2.7 m diameter reactor vessel with penetrations for 55 aluminum calandria tubes. Fifty-four calandria tubes are installed, each containing a zirconium-alloy pressure tube. The pressure tubes surround the fuel. During reactor operation, heavy water moderator partially fills the reactor vessel and surrounds the 54 installed calandria tubes.

A mixture of hydrogenated terphenyls is the coolant for all but two of the reactor sites. The exceptions are a special loop facility for light-water experiments (the WR-1L2 loop) and a pneumatic capsule not available for controlled, long-term corrosion tests as the chemistry conditions of the loop were dictated by the requirements of other experimental programs.

A schematic of the WR-1 reactor core lattice is shown in Figure 1. The small circles are positions that can accommodate 89.3 mm diameter pressure tubes, while the larger circles show positions that can accommodate 103 mm diameter pressure tubes. Two types of fuel are currently in use in WR-1. All channels can accommodate the driver fuel (UC or UO_2) but only the large diameter channels can accommodate the fast neutron (FN) fuel. The dimensions and power ratings of these fuels are given in Table 1. The UC driver fuel central support tube (CST) has an inside diameter of 45.2 mm. This makes it attractive for use with in-core facilities. A cross section of this type of fuelled pressure tube is shown in Figure 2. The fuel is supported on a CST which seals to the top of the pressure tube.

In the core of a nuclear reactor, fast neutrons (energy > 1.0 MeV) are the greatest source of irradiation damage to reactor structural materials. The FN fuel was developed to allow the study of reactor materials under a fast neutron flux density greater than that delivered by either of the driver fuels. For example, the maximum fast neutron flux density in the centre of a CST is 5.4×10^{17} neutrons/($m^2 \cdot s$) for the FN fuel as opposed to 4.1×10^{17} and 3.2×10^{17} neutrons/($m^2 \cdot s$) for the standard UC and UO_2 driver fuels respectively.

Currently, four channels in WR-1 contain FN fuel but they are occupied by two Material Irradiation Facilities and two Uniaxial Creep Rigs. Therefore, because of the higher fast neutron flux density delivered by the UC fuel and the larger I.D. of its CST, it was decided to utilize the CST of a UC-fuelled channel to contain the corrosion facility.

TABLE 1

DIMENSIONS AND POWER RATINGS OF WR-1 FUELS

Characteristic	Driver Fuel		FN Fuel
	UC	UO_2	
Length of element, mm	493	493	414
Sheath, O.D., mm	138	134.5	100.8
Length of fuel bundle, mm	495.3	495.3	419.1
Fuel bundle, O.D., mm	81.3	81.3	101.6
Elements per bundle	14	18	25
Rings of elements per bundle	1	2	1
Bundles per fuel string	5	5	4
Fuel rating per element Q/4M(W/cm) max.	55	35.8	50
O.D. of CST, mm	49.8	15.2	76.8
I.D. of CST, mm	45.2	12.7	71.0
Max. linear bundle power rating kW/m	968	810	1571
Total max.power output, MW	1.4	1.12	2.27

3. WR-1 CORROSION TEST FACILITY

The design ground rule for the WR-1 corrosion test facility was that it be an independent system. It was to be totally self-contained, with separate pumps, pressure control, temperature control, chemistry control and monitoring instruments.

Initially, a facility was envisioned which would have an electric heater to raise temperature and control pressure and a heat exchanger to remove the gamma- and neutron-generated heating within the insert. Using high-pressure, low-head centrifugal pumps, sufficient flow would be maintained in the facility to minimize the temperature differential across the insert. The cost of fabricating the heaters and purchasing the necessary high pressure pumps was, however, considered excessive.

An alternative concept was ultimately adopted. In this design the cooling water would be circulated through the insert by one of two relatively inexpensive adjustable-stroke simplex piston pumps and the flow would be controlled by the stroke of the pump. The water flow through the insert would control the rate of removal of heat from the gamma- and neutron-heating of the in-core material inventory of the facility, which in turn would control the temperature of the cooling water. It was felt that parallel circulating pumps, one operating and the other on standby, would be sufficiently reliable to provide satisfactory coolant flow.

In this design there would be a temperature gradient along the length of the insert and it would be necessary to install four thermocouples in the insert (along with the corrosion specimens) to monitor the gradient.

The in-core or insert portion of the corrosion facility was designed to fit inside the 45.2 mm inside diameter of a 14-element UC driver fuel CST. This required that the inside diameter of the corrosion insert be quite small, 24.0 mm diameter. Because the rate of neutron- and gamma-heating obtained in the insert was low, 6.2 kW, the coolant flow had to be very low to obtain the temperature gradient required. Due to the flow, the temperature and pressure control valve seats, the flow measurement orifice and the other in-line hydraulic devices required very small passages. To minimize corrosion products in the system and ensure that the valves, orifices, etc. would not become blocked, stainless steel was selected for all loop components in contact with the cooling water.

3.1 GENERAL DESCRIPTION

The WR-1 corrosion test facility is shown schematically in Figure 3. The main components of the facility are the de-gas and make-up tank, the filter, the circulating pumps, the accumulator, the corrosion insert, the pressure relief devices, the heat exchanger and the sampling system. Automatic control is provided for the insert outlet pressure and the insert temperature. The pressure relief devices include a rupture disc and relief valve on the outlet of the corrosion insert and a relief valve on the de-gas and make-up tank.

The de-gas and make-up tank is filled with distilled water from the WR-1 reactor distilled water system. The circulating pumps (one operating and one standby) draw water from the de-gas and make-up tank through the filter. This water passes through or around the insert, through the heat exchanger and through the pressure control valve before re-entering the de-gas and make-up tank. The temperature control circuit proportions the water flow through and around the insert depending on the temperature of the water within the insert.

The corrosion test insert is basically a pressure containment vessel (liner) which mounts in and seals onto the uranium carbide fuel CST and a coupon support assembly which mounts within the liner. The annular space between the liner and CST above the reactor core is filled with a shield plug assembly containing vent passages and is vented through the liner support assembly to the reactor upper service space.

The coupon support assembly seals into the liner top flange to provide a pressure-containing assembly. The cooling water inlet tube which extends the length of the liner acts as the coupon support.

Corrosion coupons are mounted either within the liner on this support tube or on the outer surface of the liner in the annular space between the fuel CST and the liner. A CO_2 purge is provided between the insert liner and the CST. This provides an environment for monitoring the resistance of corrosion coupons to the combined effects of irradiation and CO_2.

This facility will irradiate corrosion coupons in a controlled chemistry water environment at pressures up to 16 MPa(gauge) and temperatures up to 325°C. The requirements of ASME Boiler and Pressure Vessel Code Section VIII Division 1 and ANSI Power Piping Code B31.1 have been satisfied in the design.

3.2 PRESSURE CONTROL

Pressure control in the corrosion test facility is achieved through use of the positive displacement circulating pumps, the accumulator and the pressure control valve. Variable-stroke positive-displacement pumps are provided to circulate the cooling water. The pumps, mounted in parallel, operate singly, with the other pump on standby. The standby pump will start when a low flow is indicated by the flow instrumentation 1F. The normal total pump discharge flow is established by manual pump stroke adjustment (Reference Figure 3).

The positive-displacement pumps produce a pulsating flow which would make flow measurement and pressure measurement very unstable. The pulsations are minimized by the bladder accumulator installed on the pump discharge to act as a surge tank. To further reduce the pulsations in the pressure and flow measurements, the detectors are installed as far as possible from the pumps, and therefore provide the maximum system volume to absorb the pulsations. Both the flow element and transducer and the pressure transducer are installed on the line from the corrosion insert to the de-gas and make-up tank.

The pressure transducer is located on the cooling water outlet line from the insert. The pressure transducer signal is fed to a recorder and to the pressure controller which operates the pressure control valve to maintain the desired back pressure on the cooling water circuit. The facility pressure control is a function of the pump stroke, the gas pressure in the bladder accumulator and the operation of the pressure controller. The pump stroke and bladder accumulator pressure must be manually adjusted to ensure that the pressure controller is within its operating range for the desired insert operating conditions.

The cooling water flow element and transducer are located between the heat exchanger and the pressure control valve. The flow transducer signal feeds a meter relay with low-flow alarm and standby pump startup circuit.

3.3 TEMPERATURE CONTROL

The neutron- and gamma-heating of the material inventory in the insert and use of an ambient temperature cooling water supply results in a temperature gradient across the insert. Cool water enters at the bottom and is heated as it rises over the specimen coupons. The maximum temperature achieved in the insert is controlled by regulating the cooling water flow through the insert. Four thermocouples are installed at various elevations within the insert to monitor the temperature gradient.

The temperature control valve, 5T-CV1, is mounted in parallel with the insert. The temperature controller, 5T, monitors the temperature at a specific elevation within the insert (usually thermocouple 5T). The 5T controller output operates temperature control valve 5T-CV1, to regulate the cooling water flow.

3.4 MONITORING INSTRUMENTATION

Various instruments are provided to monitor temperatures and pressures within the facility. These instruments are summarized in Table 2.

TABLE 2

MONITORING INSTRUMENT SUMMARY

CODE	VARIABLE	READOUT
1H	De-gas and Make-up Tank Level	Panel Gauge
1P	Cooling Water Circuit Pressure	2-pen Strip Chart Recorder
2P	De-gas and Make-up Tank Pressure	Panel Gauge
1T	Return Cooling Water Temperature from Insert	6-pen recorder
2T	De-gas and Make-up Tank Temperature	6-pen recorder
3T	Cooling Water Temperature in Insert	6-pen recorder
4T	Cooling Water Temperature in Insert	6-pen recorder
5T	Cooling Water Temperature in Insert	2-pen Strip Chart Recorder
6T	Cooling Water Temperature in Insert	6-pen recorder
7T	Heat Exchanger Cooling Water Temperature	6-pen recorder
8T	Outside Liner Temperature	Manual reading
9T	Outside Liner Temperature	Manual reading

3.5 CHEMISTRY CONTROL

The water chemistry of the corrosion test facility is similar to that of a PHW reactor. The pH is maintained at 10-10.5 by additions of LiOH through the sample station. The dissolved oxygen content in the water is eliminated through use of a hydrogen cover gas on the de-gas and make-up tank.

The sample station is a glove box containing a single sample vessel. The cooling water flow is bypassed around the pressure control valve, 1P-CV1, through a restriction orifice and through the sample station and returned to the de-gas and make-up tank. The restriction orifice limits the bypass flow and minimizes pressure fluctuations during sampling (Reference Figure 3).

3.6 THE CORROSION TEST INSERT

A schematic of the corrosion test insert is shown in Figure 4. The insert is composed of two basic components; the insert liner and the sample support assembly. When these two components are sealed together by a sandwich seal they form a pressure vessel designed to contain the facility cooling water. These components are discussed in detail in the following sections.

3.6.1 The Corrosion Test Insert Liner

A detailed cross section of the insert liner is shown in Figure 5. It consists of a 1.0" schedule 80 Type 404 stainless steel (SS) pipe closed on the bottom end by a butt weld end cap. The outside wall of the liner is machined to provide depressions for oxidation specimens for exposure in a CO_2 environment. Each depression is continuous around the outside diameter of the liner and can hold twelve specimens.

The specimens are held in place with stainless steel straps. The selection of 25 mm pipe* was necessary so as to provide an adequate vent area between the liner and the inside wall of the fuel CST in the event of a liner failure, with its associated steam generation.

The insert is so small that additional shielding is required to prevent radiation streaming from the annular space between the liner and the CST. The shielding plug is a sleeve machined from Type 304SS hollow bar. An irregular shape is specified for the sleeve to ensure adequate shielding while also providing adequate vent flow area. The sleeve is welded to the insert closure flange.

The insert support flange is welded to the top of the shielding sleeve below the insert closure flange. This flange seals to the CST and supports the entire corrosion test insert. The CST vent area is provided by an annular space between the support flange and the shielding sleeve and relieves to the reactor upper service space through eight holes drilled radially into the annulus above the support flange. The support flange has six holes through which cap screws connect it to the CST.

A CO_2 gas purge line runs into the annulus through a hole drilled at 45° above one of the vent holes. The purge line extends to the bottom of the insert and provides both the CO_2 environment for the oxidation samples strapped to the outside of the liner and thermal insulation between the insert and the CST.

Two thermocouples at different elevations are used to measure the temperature of the CO_2 environment in the space between the linear and the CST. These thermocouples enter this space via one of the vent holes in the insert support flange.

The insert closure flange at the top of the insert liner is a Type 304SS welding neck flange welded to the top of the radiation shield.

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* Nominal 1.0" schedule 80 pipe

It contains six bolt holes through which cap screws connect it to the closure flange of the sample support assembly (see subsection 3.6.2). A sandwich seal of soft iron or annealed mild steel provides the pressure boundary at the joint.

Figure 6 is a photograph which shows both the closure flange and the support flange of the insert liner. The annular space between the shielding sleeve and the support flange is clearly visible as are the vent holes (from the CST) through the support flange. The small gauge tubing in the background is the CO_2 purge line. Figure 7 shows the depressions for containing the CO_2 oxidation specimens. This figure also shows the CO_2 purge line.

3.6.2 The Sample Support Assembly

This assembly contains the upper insert closure flange, the cooling water inlet and outlet ports, the sample support tube and the penetrations for the four insert temperature thermocouples. A detailed schematic of the sample support assembly is shown in Figure 8.

The closure flange seals to the insert liner with a sandwich seal. There are two spigots on the bottom of the closure flange. One is to center the flange in the insert liner and the other is to center the sandwich seal.

The vertical rectangular extension on the closure flange contains both the water inlet and outlet ports and the thermocouple penetrations. Three 19 mm-diameter holes are drilled up the central area of the rectangular extension. Two of these are the water supply and return connections. These connections are made with Grayloc blind hubs which are welded to the flat faces of the rectangular extension. Holes are drilled to connect each with one of the longitudinal holes drilled in the vertical extension.

The four thermocouples are inserted through 2.82 mm Swagelok fittings notched into the side of the vertical extension. Four holes are drilled from each fitting at a 45° angle to intersect with the third longitudinal hole in the vertical extension.

The water inlet penetration on the lowest spigot is counter-bored to accept a 9.53 mm O.D. x 1.24 mm wall Type 304SS tube. The inlet water tube is welded into this hole and is bent to the center of the spigot. This tube is connected to the sample support tube with a 9.53 mm SS Swagelok union. The sample support extends to within 50 mm of the bottom of the corrosion insert liner.

The water inlet tube is used to support the test specimens in the core region of the insert. Twenty-four specimen mounts, each capable of holding four specimens, are provided on the outside of the water inlet tube. The specimen mounts are installed back-to-back in groups of two, occupying 166 mm of tube length per pair. A gap of 74 mm is left between pairs to allow for specimen installation and removal. Twelve pairs of specimen mounts occupy 2800 mm of the water inlet sample support tube length. This completely covers the reactor core region.

Each specimen mount consists of a backing washer, three specimen mounting brackets and locking disk with cotter pin. The three specimen mounting brackets are shaped and mounted as shown in Figure 8. The specimens mount in a square array around the outside of the water inlet tube and are retained in position by the locking disc and cotter pin.

The four insert temperature thermocouples can be installed at any elevation desired to monitor any portion of the insert temperature gradient. Once the thermocouples are installed in the desired position, the leads are banded to the water inlet pipe between specimen mount assemblies and at intervals in the region above the specimens. The bands are lengths of stainless steel wire.

The thermocouple leads external to the insert are terminated in a plug connector which is extended above the insert and the upper service space insulation on threaded rods. A jumper cable connects the insert thermocouples to a wall-mounted junction box.

Figure 9 is a photograph showing the upper closure flange, thermocouples, thermocouple plug connector and the water inlet and outlet ports. Figure 10 shows a typical assembly of mounted specimens and also demonstrates how the thermocouples are wired to the inlet water pipe.

3.6.3 Corrosion Specimens

Specimens may be exposed in either a water or a CO_2 environment. The dimensions for the water phase specimens are 76.2 mm x 6.35 mm x 1.52 mm thick, and for the CO_2 phase specimens are 50.80 mm x 6.35 mm x 1.52 mm thick.

4. OPERATING EXPERIENCE

The corrosion facility has now operated satisfactorily since March 1976. Before that, some difficulties were experienced due to the close fit of the original specimen holder in the insert liner. This report describes the modified specimen holder currently in use. The four thermocouples are placed in the reactor core area of the insert so as to obtain the best possible estimate of the temperature gradient in the core. Since the out-core temperature is not monitored, no provision has been made in the current specimen holder for out-core specimens.

A typical temperature profile obtained during an exposure is shown in Figure 11. It has been found that the temperature control system is very sensitive and allows very quick attainment of the temperature range desired.

At each scheduled reactor shutdown (every three months) the sample support assembly is freed from the insert liner and taken to the universal hot cells. The corrosion specimens are removed, cleaned, weighed and either returned to the insert or replaced. This has proved to be a simple operation.

If any of the thermocouples on the sample support assembly are not operating satisfactorily, all four of them are replaced. In this case the old thermocouples are removed, and the closure flange is removed from the sample holder (by disconnecting the 9.53 mm Swagelok fittings) and decontaminated. This allows the four replacement thermocouples to be inserted through the flange and to be connected to the thermocouple plug connector outside the universal cells. The flange is then returned to the cells and reconnected to the specimen holder, and the thermocouples strapped to the holder. The strapping operation is time-consuming and has proved to be the insert's most difficult operational problem.

The practice of exposing specimens to the CO_2 environment between the liner and the CST has been discontinued. It proved very difficult (but not impossible) to replace specimens in the machined depressions on the outside surface of the liner with remote manipulation in the universal cells.

5. NEUTRON FLUX DENSITY AND DISTRIBUTION

Figure 12 shows a profile of the average fast neutron flux density (> 1 MeV) in the centre of the corrosion test facility for one month's operation of the WR-1 reactor calculated using the LATREP computer code[5]. It has already been shown for the Materials Irradiation Facilities that these computed values agree within 10% of fast neutron flux densities determined by irradiating iron flux monitors in the facilities[4].

6. CONCLUSIONS

The corrosion facility operates satisfactorily. A typical temperature gradient in the insert from the bottom to the top of core is 245 to 280°C. This range can be attained without difficulty.

Temperature and pressure control is excellent.

The specimens are easy to remove and replace.

The corrosion specimens can receive a fast neutron flux density as high as 2.65×10^{17} neutrons/($m^2 \cdot s$) (> 1 MeV) at the centre of the fuel string.

The replacement of the insert thermocouples is the most difficult operational problem.

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3. K. Nuttall, AECL Report in preparation.

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5. I.H. Gibson, "The Physics of LATREP", Atomic Energy of Canada Limited, Report AECL-2548 (1966).

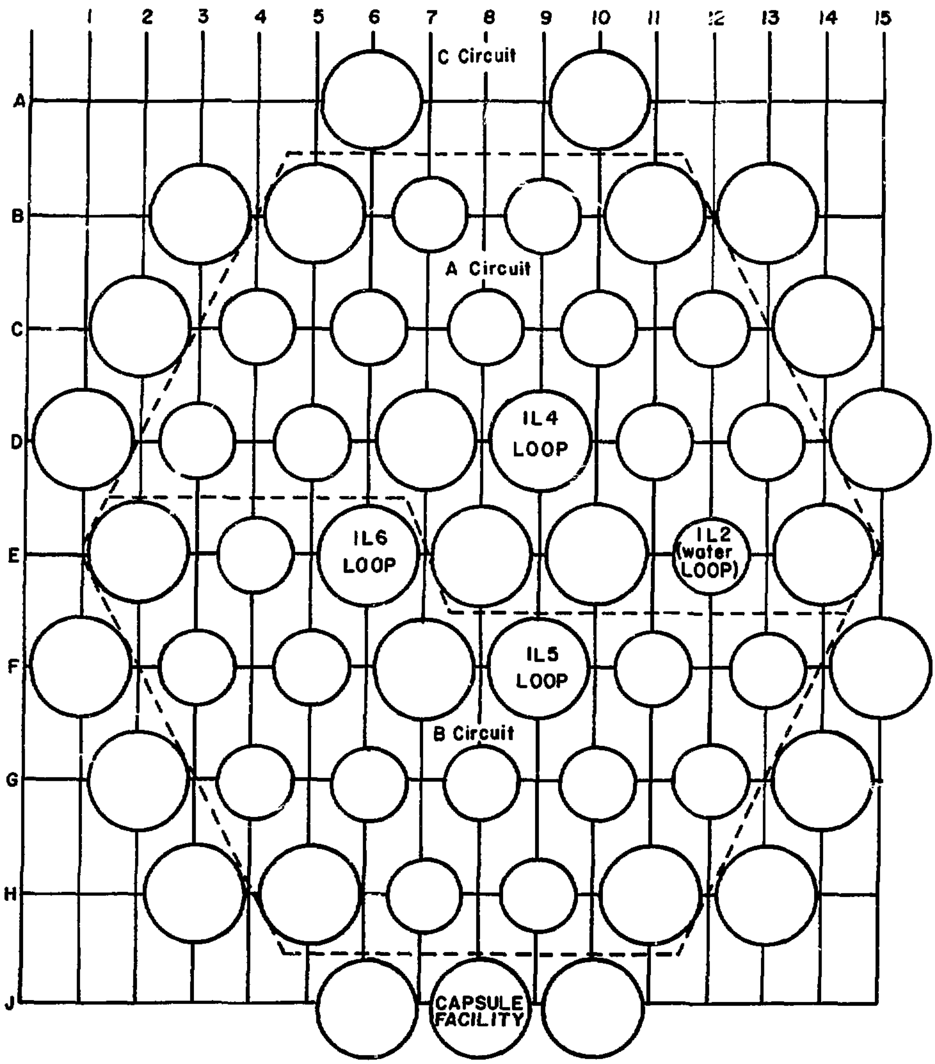


FIGURE 1: SCHEMATIC OF WR-1 REACTOR CORE LATTICE.

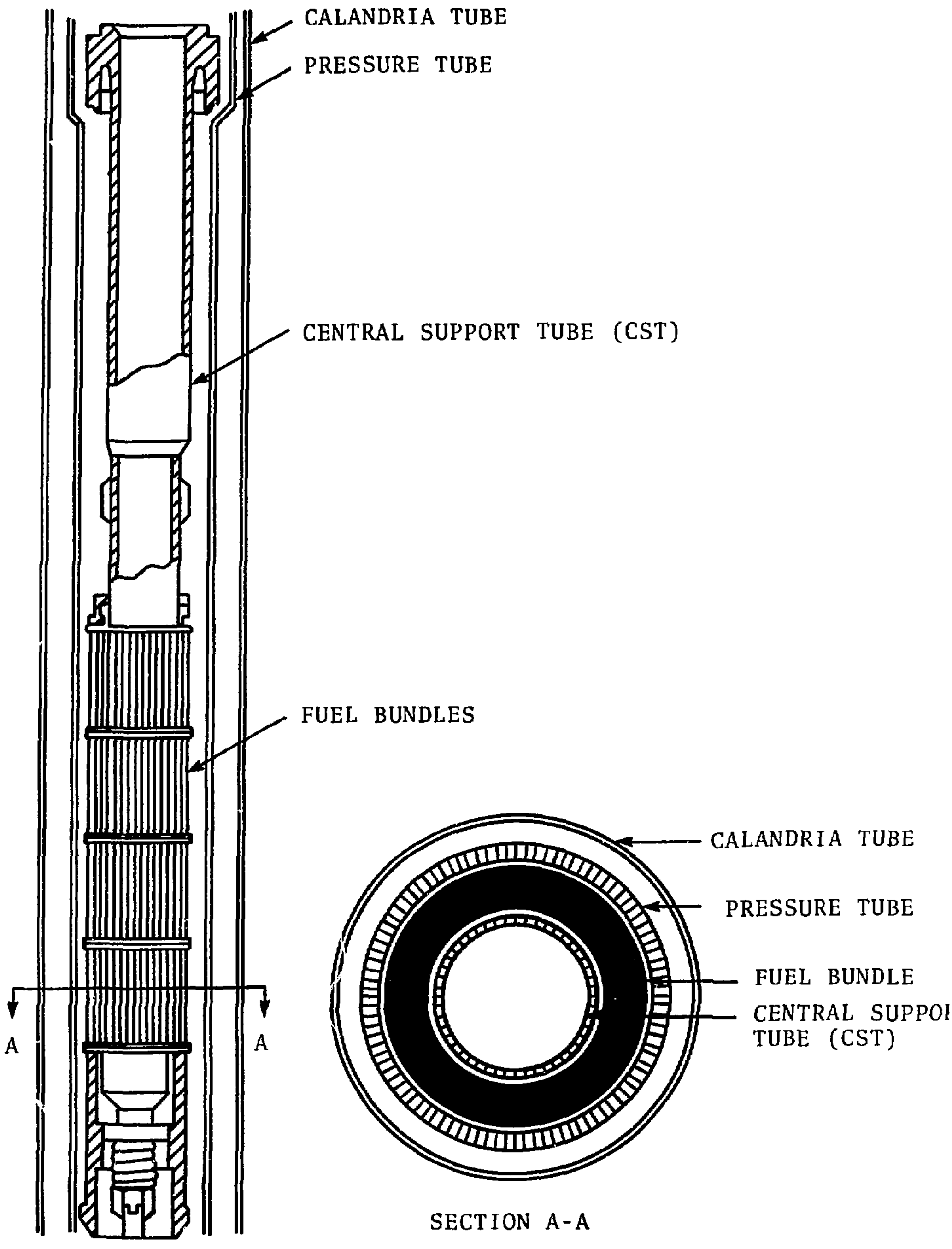


FIGURE 2: FUELLED PRESSURE TUBE.

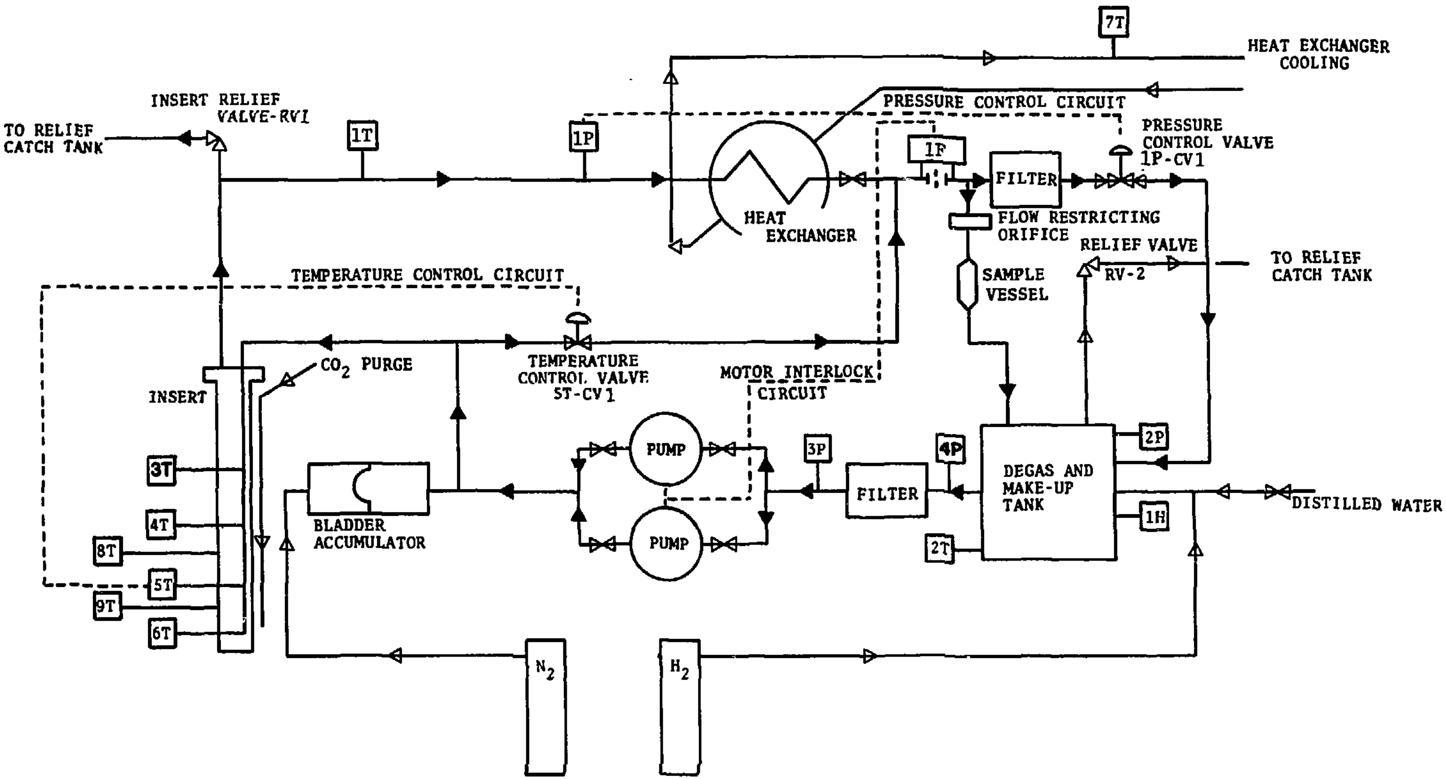


FIGURE 3: WR-1 CORROSION TEST FACILITY.

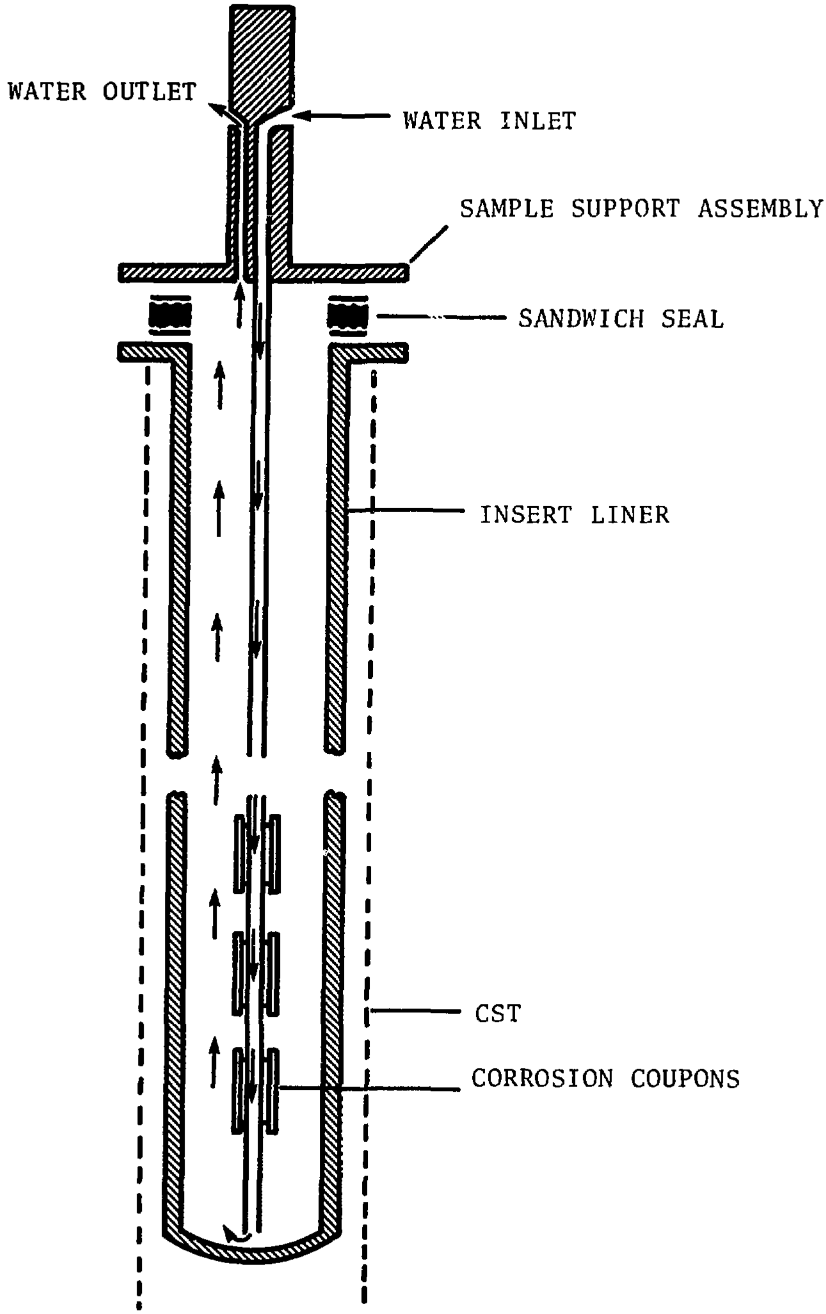


FIGURE 4: SCHEMATIC OF CORROSION TEST INSERT.

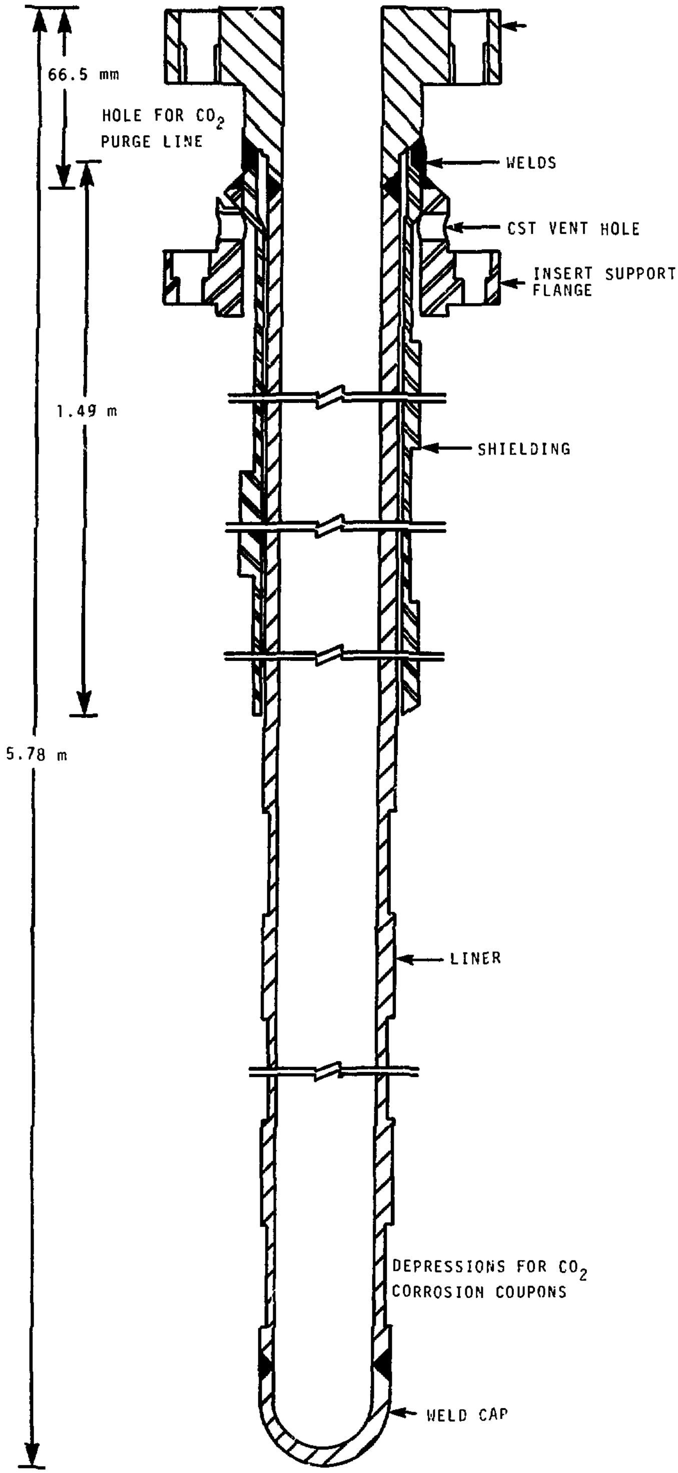


FIGURE 5: CROSS SECTION OF INSERT LINER

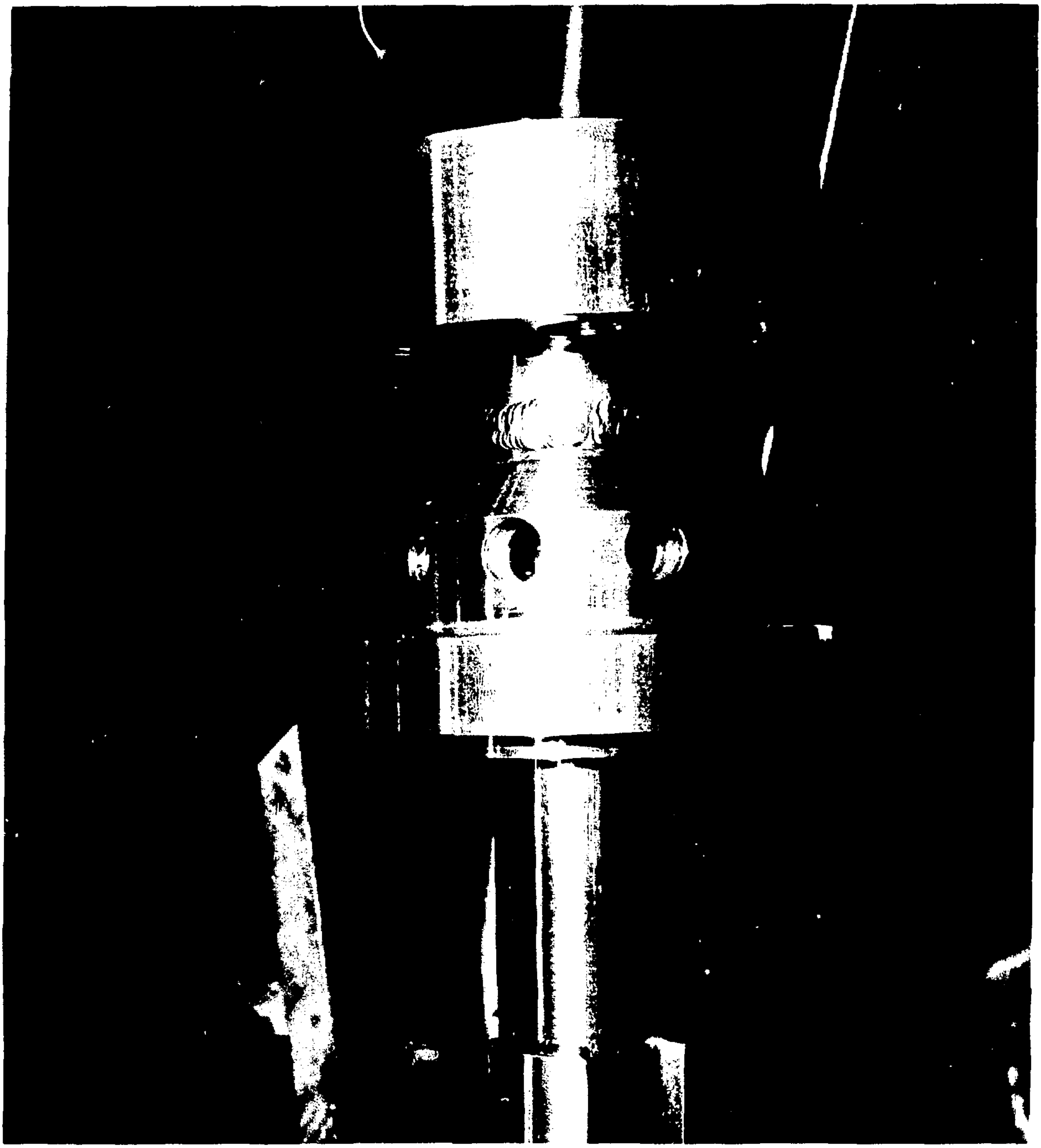


FIGURE 6: CLOSURE AND SUPPORT FLANGES OF INSERT LINER.

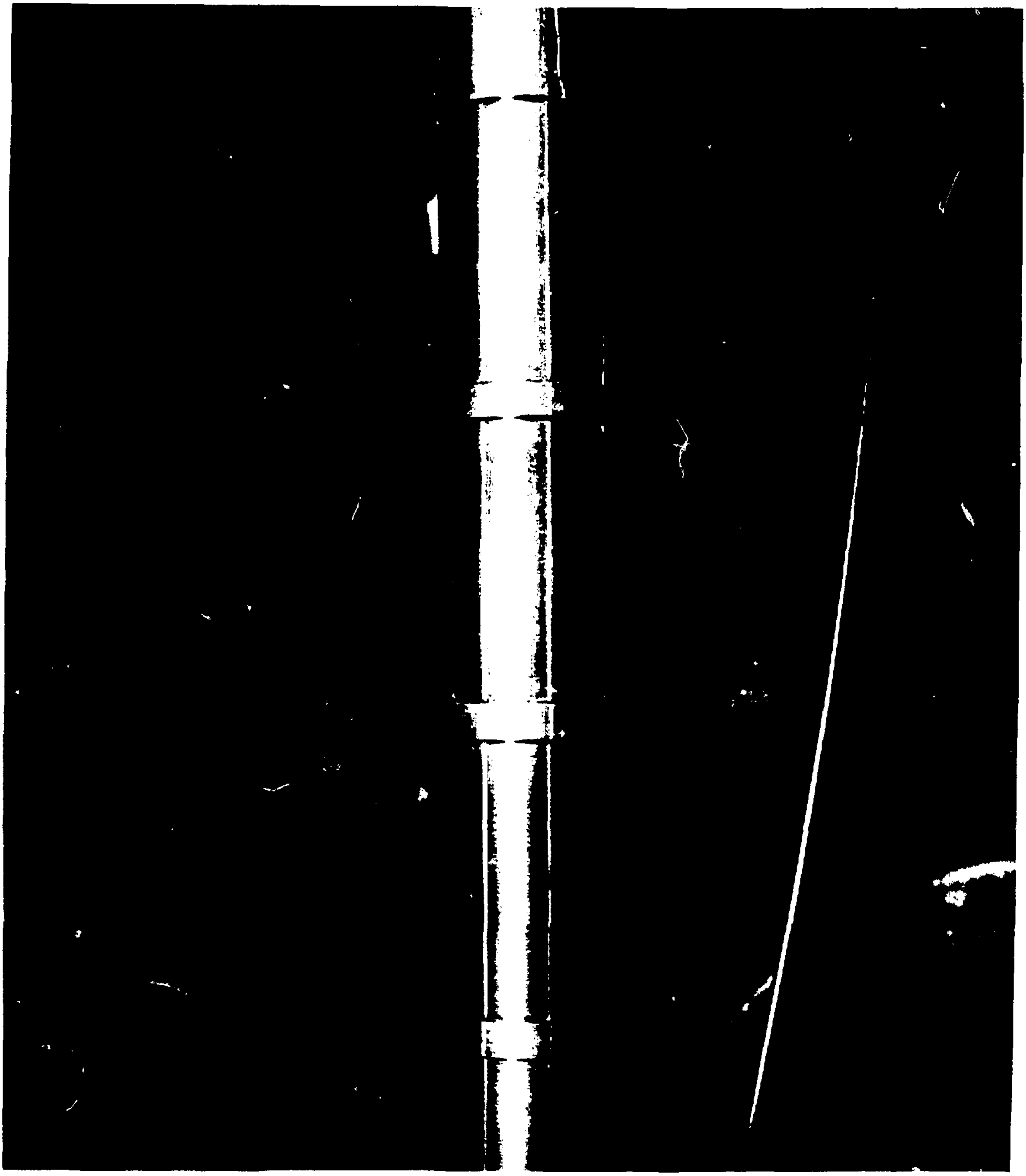


FIGURE 7: DEPRESSIONS FOR CO_2 OXIDATION SPECIMENS.

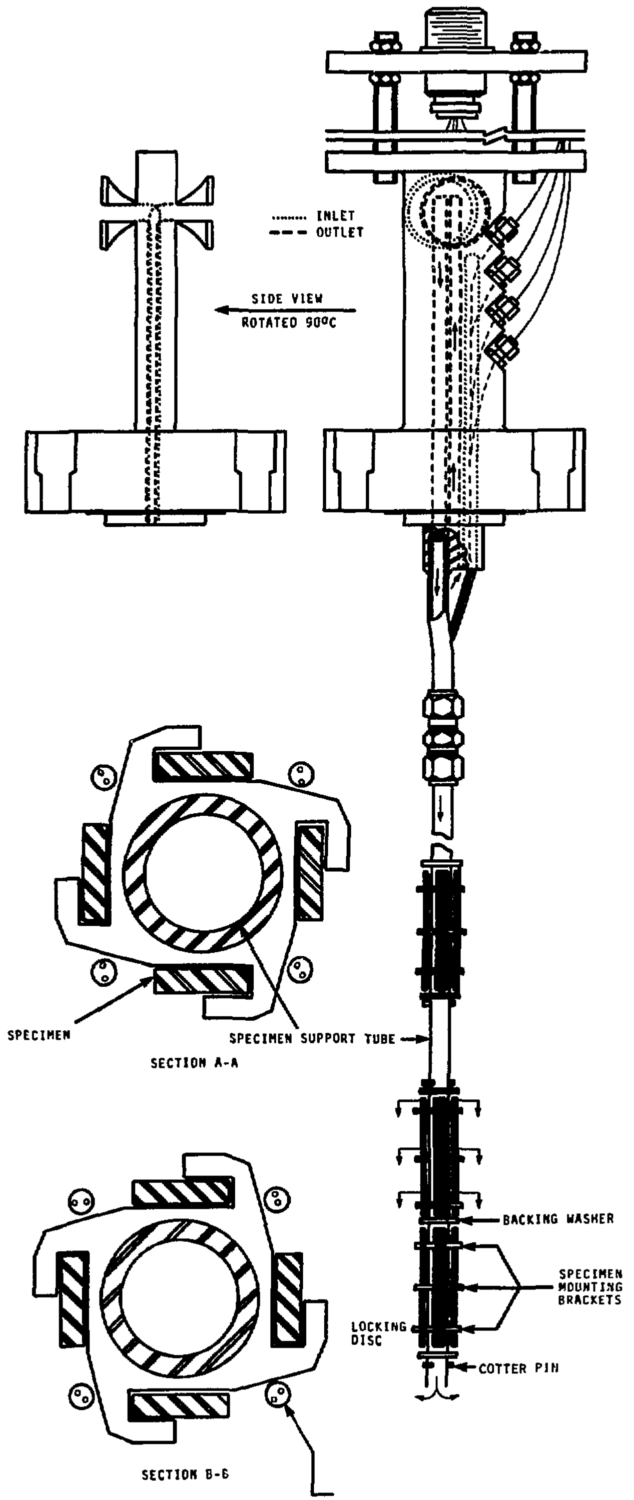


FIGURE 8: SCHEMATIC OF SAMPLE SUPPORT ASSEMBLY.

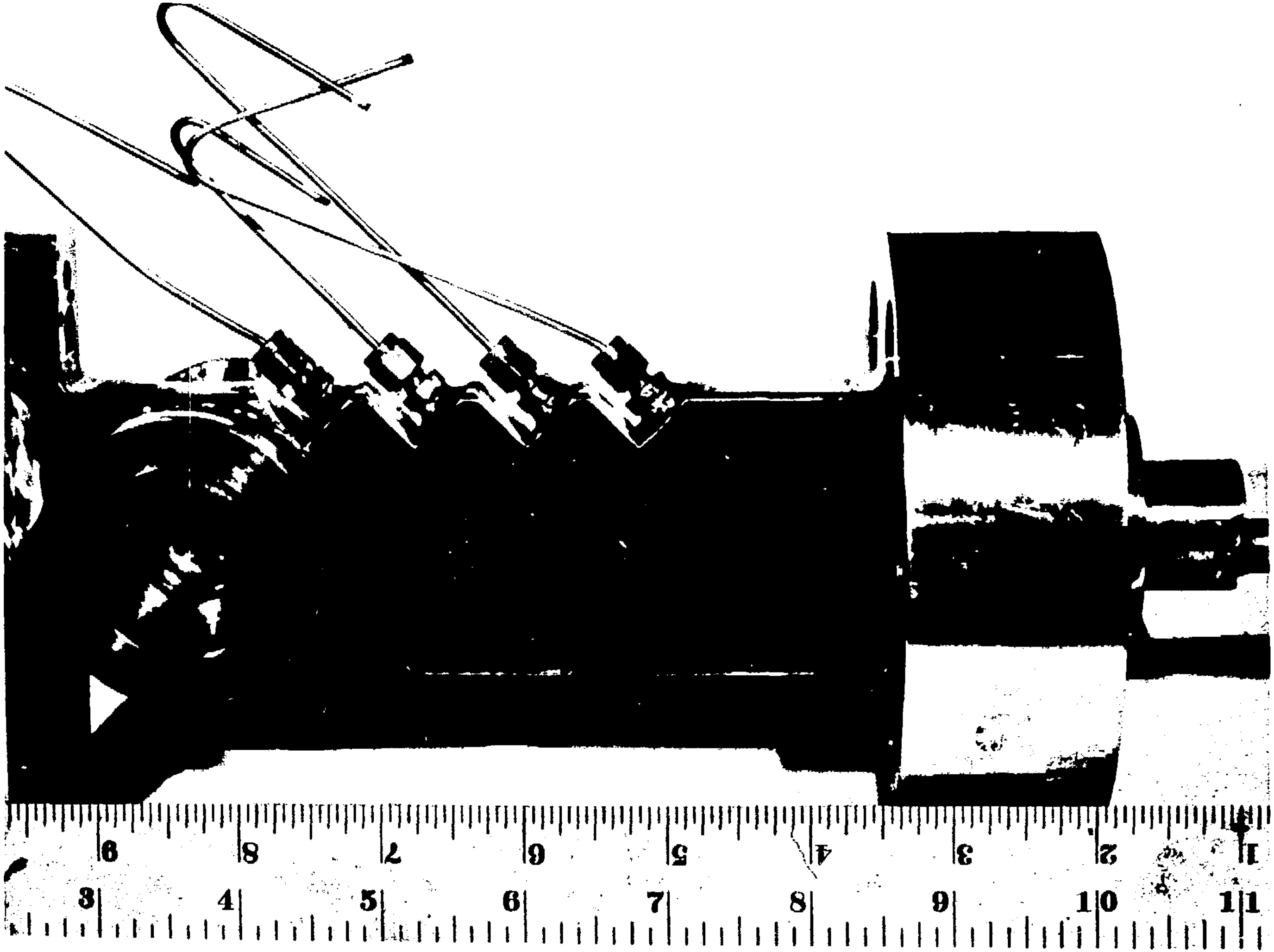


FIGURE 9: UPPER CLOSURE FLANGE, THERMOCOUPLES, THERMOCOUPLE PLUG CONNECTION AND WATER PARTS.

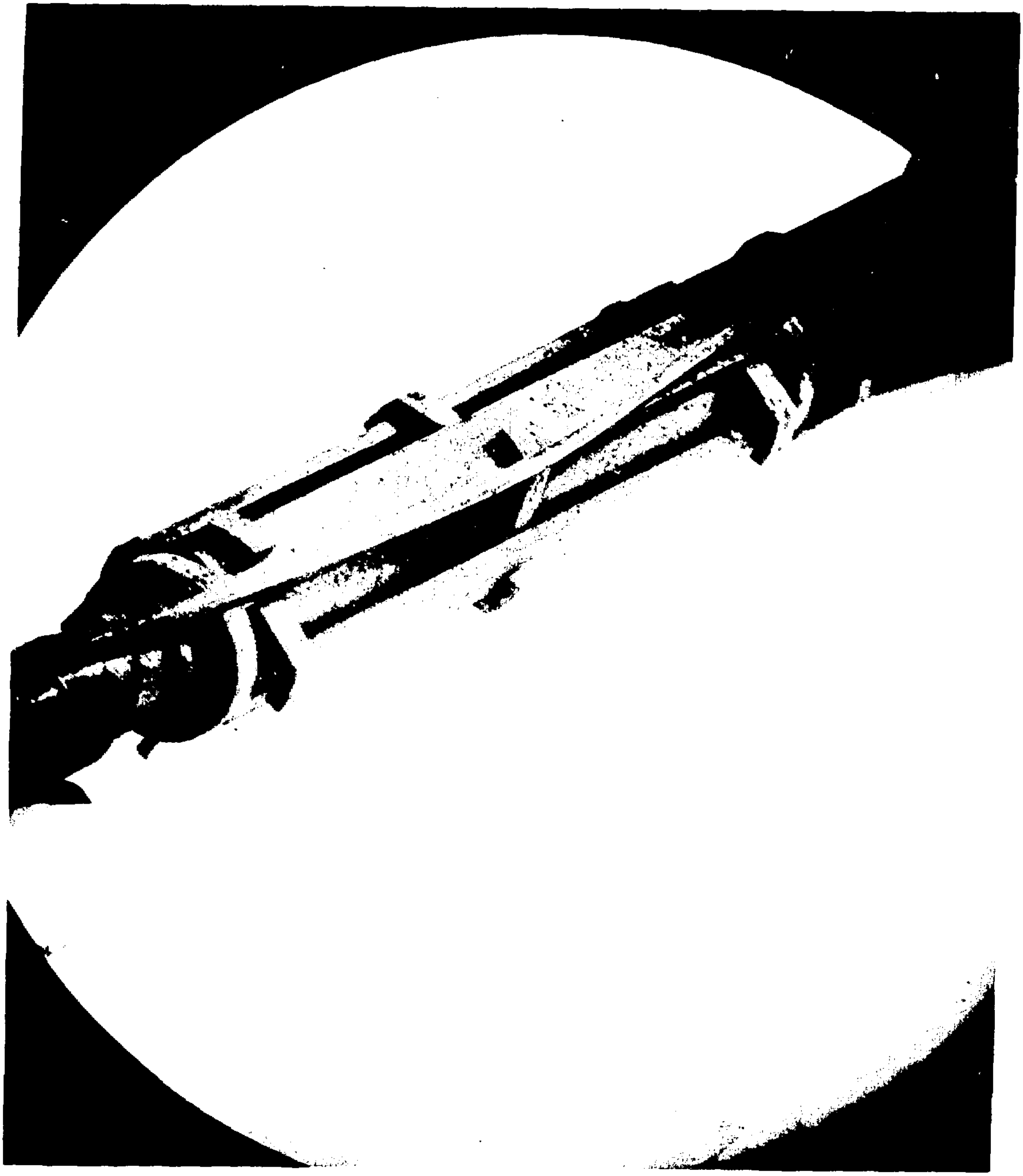
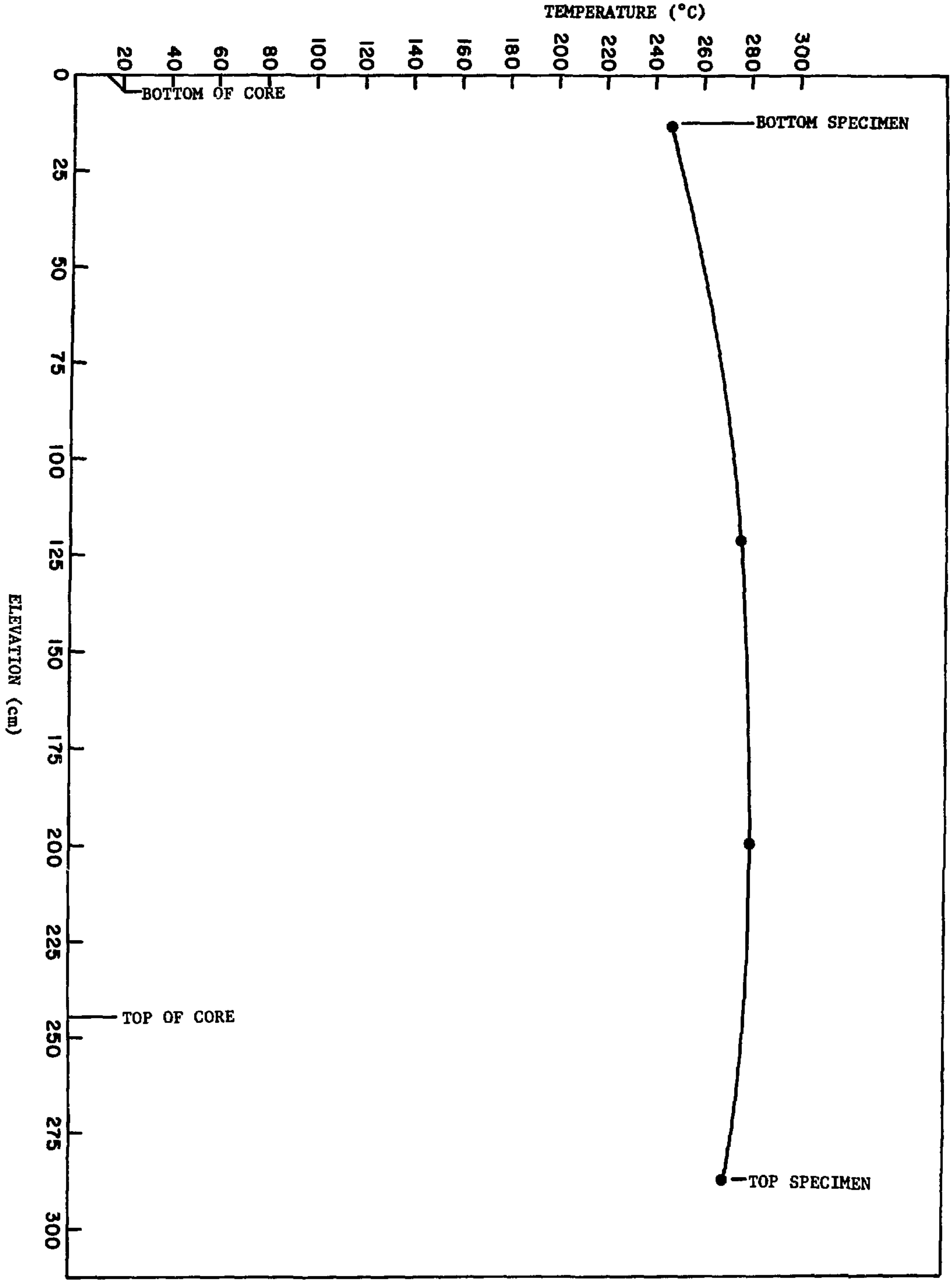


FIGURE 10: TYPICAL ASSEMBLY OF MOUNTED SPECIMENS.


TEMPERATURE (°C)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
0
25
50
75
100
125
150
175
200
225
250
275
300
ELEVATION (cm)
BOTTOM OF CORE
TOP OF CORE
BOTTOM SPECIMEN
TOP SPECIMEN

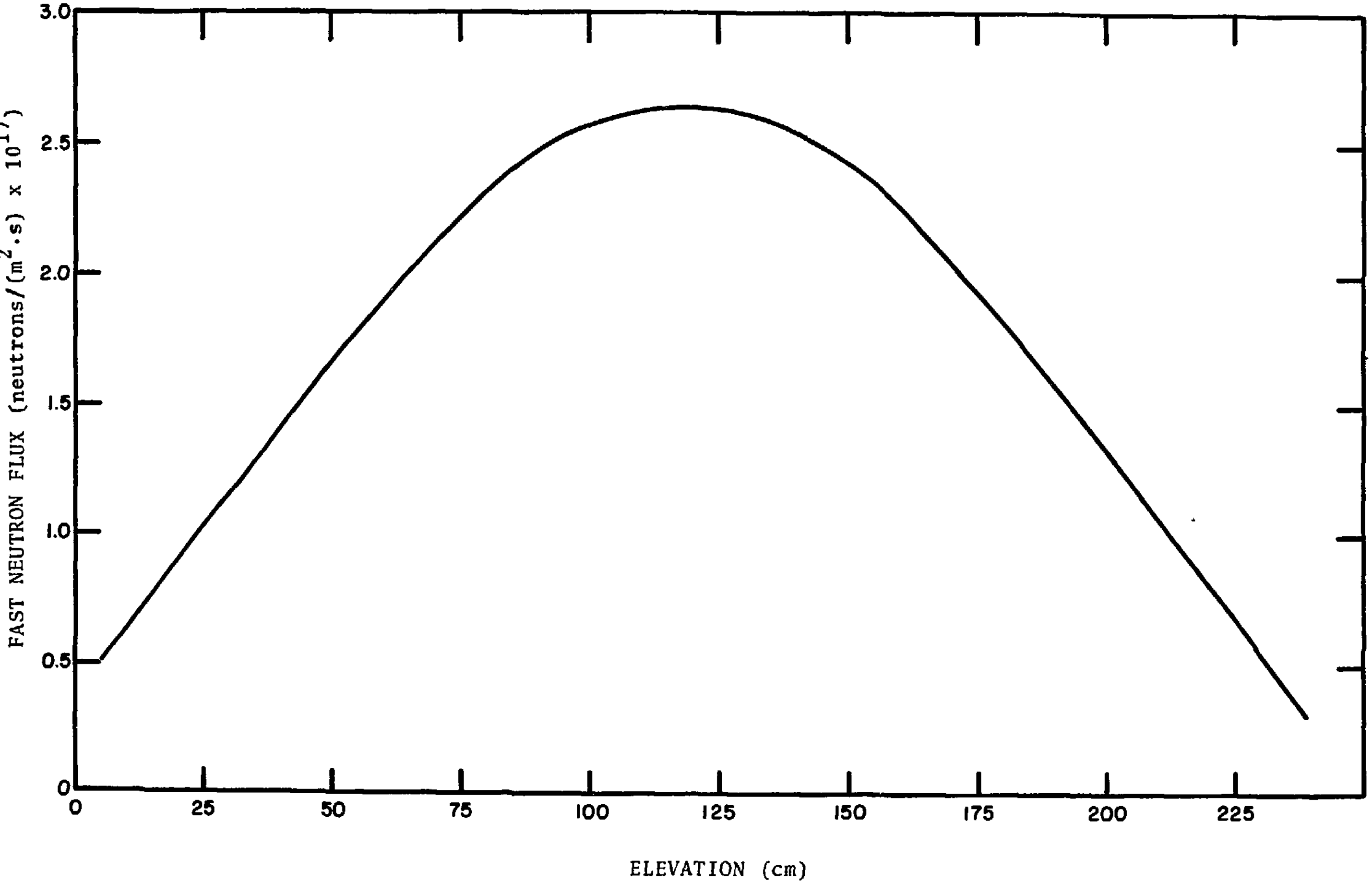


FIGURE 12: PROFILE OF AVERAGE FAST NEUTRON FLUX DENSITY.

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